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QUARTERLY TECHNICAL PROGRESS REPORT

FOR PERIOD ENDING SEPTEMBER 30, 1966

SNAP-50/SPUR CONRACT AF 33(615)-2326

BPSN: 5(6399-675A)63409124

OCTOBER 15, 1966

WAED 66.52E

Westinghouse
ELECTRIC CORPORATION
AEROSPACE ELECTRICAL DIVISION
LIMA, OHIO

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FOREWORD

This Quarterly Technical Progress Report describes work conducted on the SNAP-50/SPUR Generator Development Program by the Westinghouse Aerospace Electrical Division during the period from July 1, 1966, to September 30, 1966, under United States Air Force Contract AF33(615)-2326.

This contract provides for the continued development of the a-c generator for the SNAP-50/SPUR powerplant and represents a continuation of development work performed on Contract AF33(615)-1551.

Program progress is presented in Section II for four development tasks.

Members of the Westinghouse Systems Research and Development Department assisting in the preparation of this report include D. R. Basel, R. W. Briggs, C. M. Gauthier, J. G. Hoop, A. E. King, C. C. Kouba, A. J. Krause, J. L. McCabria and P. H. Scheffler.

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SECTION I

INTRODUCTION

The Space Power Unit Reactor (SPUR) program was initiated by the United States Air Force, in cooperation with the Atomic Energy Commission in 1960. The objective of this program is to develop a long-life nuclear-dynamic space power system capable of supplying 300 kilowatts of electric power.

The power system consists of a nuclear reactor as a heat source, a thermodynamic conversion system for converting thermal energy to mechanical energy, an electromagnetic a-c generator for obtaining electrical power, radiators for rejecting waste heat, and system controls and auxiliary equipment.

The objectives of the present program are to continue the study, experimental and development programs for the a-c generator and its controls which have been progressing sequentially under contracts AF33(615)-7379, AF33(616)-8322, AF33(657)-8954, AF33(657)-10922 and AF33(615)-1551.

Major generator development tasks consist of:

1. generator bore seal development
2. generator stator development
3. generator rotor development
4. full scale, 467kva generator development

Technical progress is reported herein for each of these efforts.

SECTION II

TECHNICAL DISCUSSION

A. TASK 2.4.1 - BORE-SEAL DEVELOPMENT

1. Past Quarter's Accomplishments

Micrographic examinations were made on the ceramic to metal brazed joints of the 2.5-inch diameter bore-seal specimens which had simultaneous exposure to liquid and vapor phases of potassium at 1100°F for 1000-hours.

Four additional trial brazing runs were made to develop techniques for fabrication of 11.5-inch diameter tubular ceramic-metal assemblies incorporating potassium resistant materials suitable for use in generator bore-seals of that diameter.

a. Evaluation of 2.5-Inch Tubular Specimens

Photomicrographs of brazed joint sections after exposure for 1000-hours at 1100°F to liquid potassium at the bottom and vapor at the top joint of the 2.5-inch diameter tubular bore-seal type specimens are given in Figures 1 through 7. The grade of ceramic, the metal end closure material, and the brazing alloy are identified for each figure. Sample No. 9 developed a leak at one point in the upper braze exposed to vapor and No. 8 was broken when the enclosing capsule was accidentally dropped in removing it from the aging oven.

b. Development of Brazing Techniques for 11.5-Inch Tubular Assemblies

As a continuation of the previously reported three initial brazing trials by Eimac Division of Varian, for fabrication of 11.5-inch tubular ceramic-metal assemblies, four more brazing runs were made using the same Ei-3 type ceramic tubes of high purity alumina and metal end members of 0.30-inch thick 99 Cb/1Zr alloy sheet. Information concerning the brazing cycles for specimens No. 4 through 7 is listed in Table I. The brazing alloy components in runs 6 and 7 were given a 28-percent copper content in place of the 17-percent used in runs 1, 2, and 3.

This was done to compensate for vaporization of a portion of the copper during heating under vacuum.

All of the above brazed assemblies leaked because of cracking in the ceramic, refractory metal, or brazed alloy components. A similar condition also developed in the small CLM-15 tensile specimens which were included in each brazing run. For this reason, the smaller laboratory furnaces used in previous brazing developments were used to make comparison check runs with CLM-15 specimens. From these trials it was found that vacuum tight joints were produced in the small CLM-15 specimens by rapid heating and cooling cycles, but leaking joints were produced in CLM-15 specimens when the laboratory furnace was operated on the slower heating and cooling cycle characteristic of the larger vacuum furnace needed for specimens with 11.5-inch diameter ceramic parts.

Funding difficulties at this time on development of bore-seal fabricating techniques precluded further effort under the contract to find a solution to these difficulties. However, discovery of another large vacuum furnace installation which would allow use of brazing alloys containing beryllium led Eimac to make a single brazing run in it with their own funding. Small CLM-15 tensile specimens brazed alone in the large furnace by use of the 75 Zr/19 Cb/6 Be alloy with a slow heating and cooling cycle, typical of that required for full-scale bore-seal assemblies, produced specimens with vacuum tight joints. This spot check is a note of promise for possible future developments. The zirconium base alloy containing beryllium had been the first choice from earlier development work in potassium exposure of brazed joints, but previous apparent lack of large vacuum furnaces in which the beryllium bearing alloy could be used had limited trial brazing of the large assemblies to the use of other alloys.

The Bore Seal Topical Report is in preparation and will include the effort concluded to date.

2. Planned Activity for Next Quarter

The Bore Seal Topical Report will be completed and distributed.

No further effort is planned because of funding uncertainties.

TABLE I

TRIAL BRAZEMENTS OF 11.5-INCH TUBULAR CERAMICS TO 0.030 Inch Cb/1Zr

Specimen Number	Braze Alloy	Brazing Cycle Temp.	Brazing Cycle Hold	Vacuum (Torr) Cold	Vacuum (Torr) Hot	Remarks
4	80Ti/20Ni	1920F	20 min.	7×10^{-7}	1×10^{-4}	Joints cracked
5	80Ti/20Ni	1920F	20 min.	1×10^{-6}	5×10^{-5}	Li_2MoO_4 precoat on ceramic joints stressed and rings cracked
6	72Ti/28Cu	1870F	15 min.	1×10^{-6}	3.2×10^{-5}	Fine cracks in braze
7	72Ti/28Cu	1870F	7 min.	5×10^{-7}	3.9×10^{-5}	Cooling held 9 hours at 1200°F Cracks in brazed joints

Vapor 300X

Liquid 300X

Figure 1. Micrographs of Brazed Joints in 2.5-Inch Tubular Ceramic-Metal Specimen No. 1 After 1000-hour Potassium Exposure at 1100°F

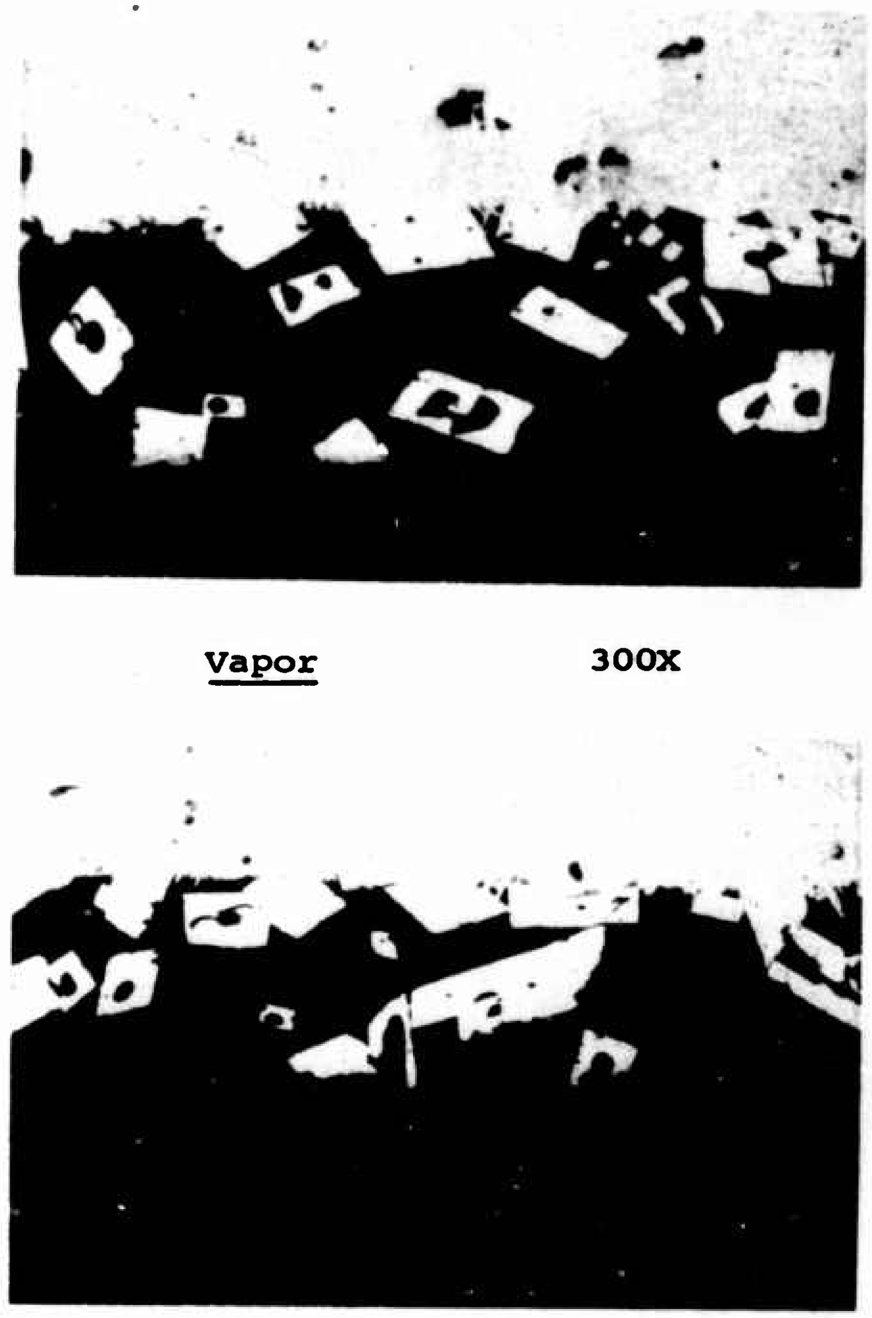
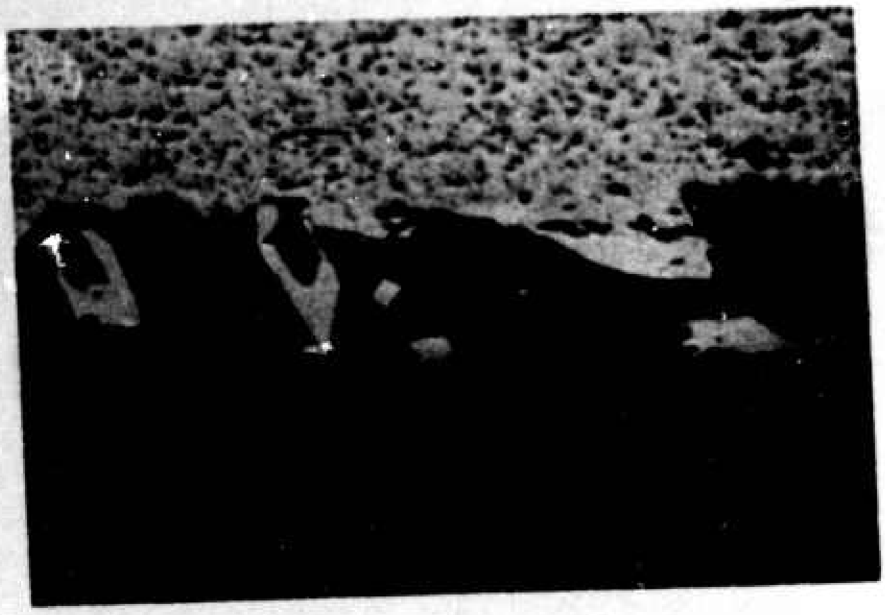


Figure 2. Micrographs of Brazed Joints in 2.5-Inch Tubular Ceramic-Metal Specimen No. 2 After 1000-hour Potassium Exposure at 1100°F



Vapor 300X

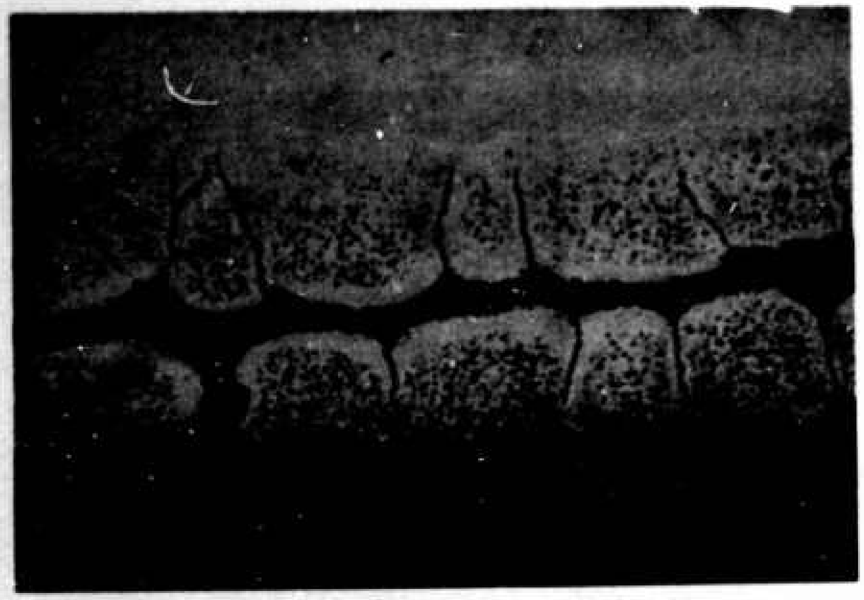
Liquid 300X

Figure 3. Micrographs of Brazed Joints in 2.5-Inch Tubular Ceramic-Metal Specimen No. 3 After 1000-hour Potassium Exposure at 1100°F

Vapor 300X

Liquid 300X

Figure 4. Micrographs of Brazed Joints in 2.5-Inch Tubular Ceramic-Metal Specimen No. 4 After 1000-hour Potassium Exposure at 1100°F



Vapor 300X

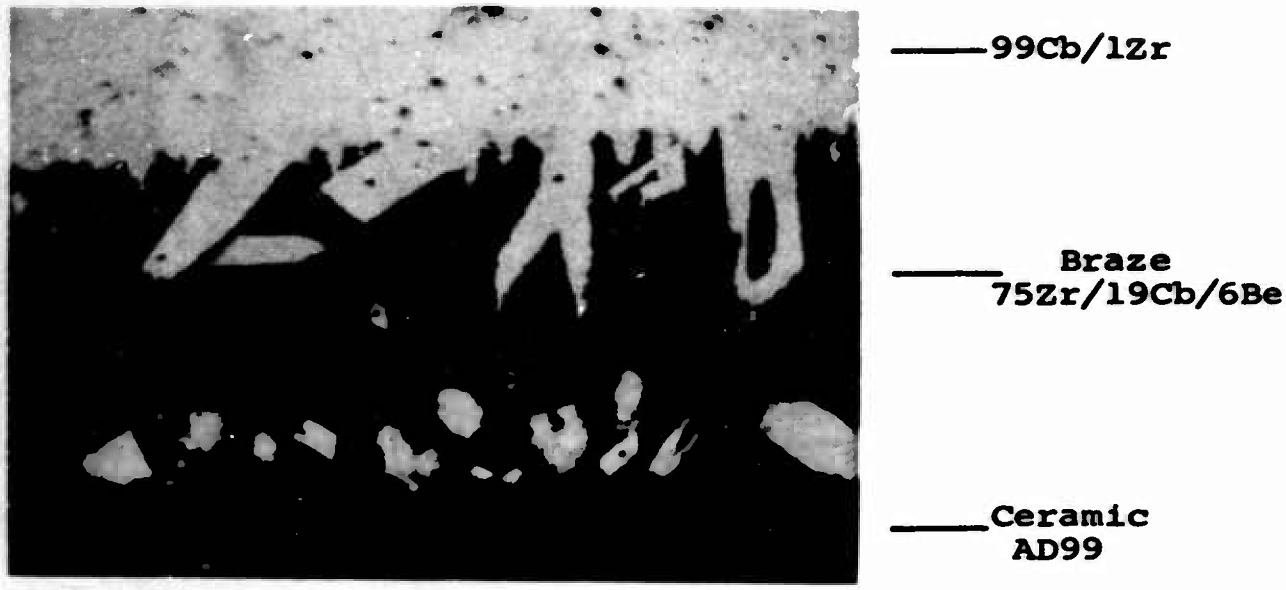
Liquid 300X

Figure 5. Micrographs of Brazed Joints in 2.5-Inch Tubular Ceramic-Metal Specimen No. 5 After 1000-hour Potassium Exposure at 1100°F

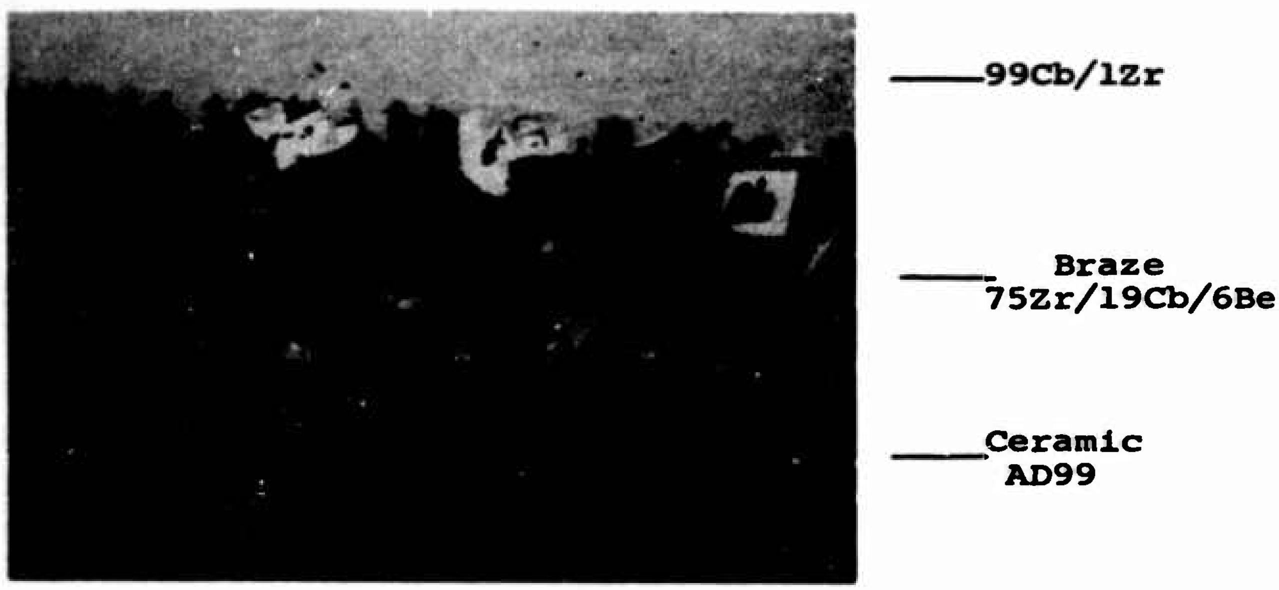
Vapor 300X

Liquid 300X

Figure 6. Micrographs of Brazed Joints in 2.5-Inch Tubular Ceramic-Metal Specimen No. 8 After 1000-hour Potassium Exposure at 1100°F



Vapor 300X



Liquid 300X

Figure 7. Micrographs of Brazed Joints in 2.5-Inch Tubular Ceramic-Metal Specimen No. 9 After 1000-hour Potassium Exposure at 1100°F

B. TASK 2.4.2 - STATOR DEVELOPMENT

1. Past Quarter's Accomplishments

a. Electrical Insulation

(1) Thermal Endurance:

Two previously described hermetically sealed test statorettes were thermally aged for a total of 10,000-hours under argon gas at 20-psia and high-vacuum while in a 600°F ambient with the test windings electrically heated to 900°F.

Representative insulation resistance values, selected at appropriate time intervals from the 160 readings taken on each winding during test, are shown in Figure 8 for the flexible and rigid forms of insulation in high-vacuum and in argon. The observed hot-resistance values are lower than the actual values because parallel leakage paths existed in the lead insulation of temperature measuring thermocouples attached to the windings. The cold-insulation resistance values (with the winding end connections clipped off at the conclusion of aging) at the right-hand edge of the plot are probably more representative of the relative resistance values in the units.

Flexible electrical insulation, consisting of double-glass serving on conductor, and slot liners of mica bonded to glass cloth by aluminum-orthophosphate, decreased by about two decades in resistance under argon and increased by about one decade in high-vacuum. Rigid electrical insulation, consisting of ceramic slot liners, showed negligible change of resistivity both in argon and in high-vacuum after long time aging.

(2) Heat Conduction:

Representative values of observed temperatures taken from statorette tests, as shown in Figure 9, give a qualitative comparison between heat transfer in argon and in high-vacuum for flexible and rigid forms of insulation. Early termination of program effort precluded making

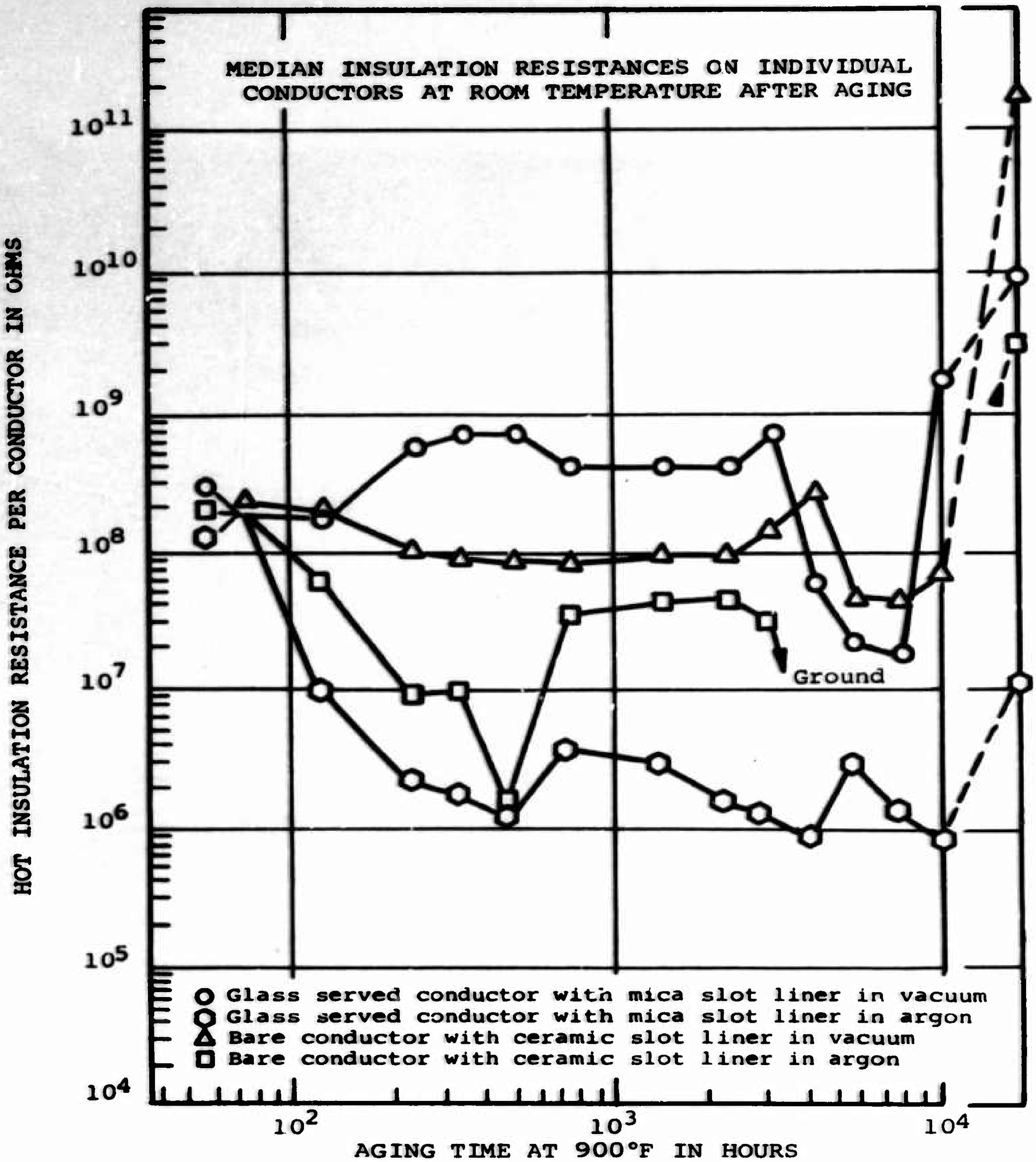
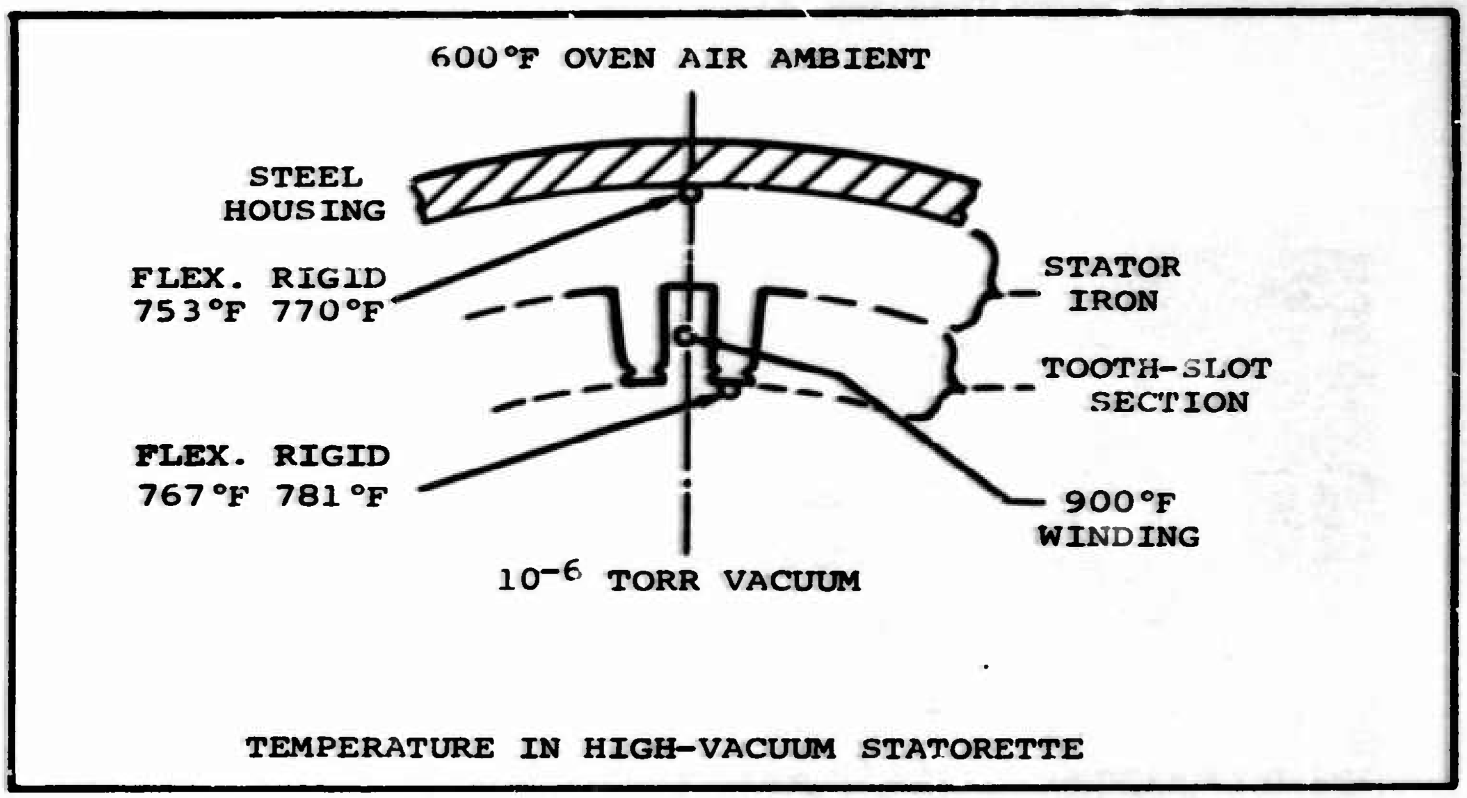
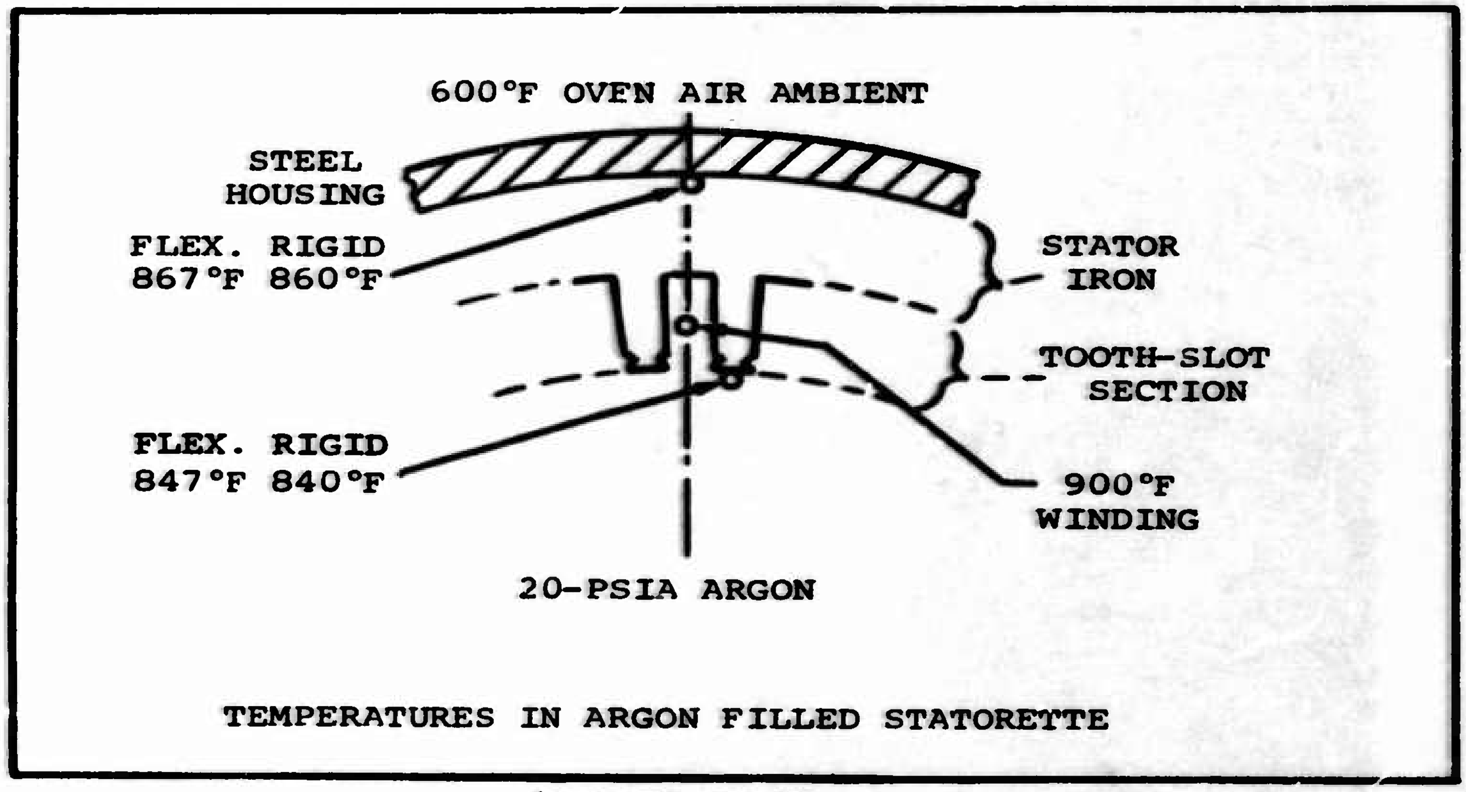


Figure 8. Effect of Time at Temperature on Stator Insulation Electrical Resistance in Vacuum and Argon





(Actual Size)

Figure 9. Comparison of Temperatures In High-Vacuum And Argon Filled Statorette Section With Flexible And Rigid Forms of Slot Insulation

of a mathematical analysis from this data. However, the temperature differentials observed indicate the order for decreasing thermal conduction to be: (a) flexible insulation in argon gas, (b) rigid insulation in argon gas, (c) rigid insulation in vacuum, and (d) flexible insulation in vacuum.

(3) Starting Voltage for Electrical Discharge:

Testing for determination of the starting voltage for electrical discharge in high-vacuum and in argon gas at atmospheric pressure was completed on the six statorettes described in quarterly report WAED 66.30E. The equipment set-up shown in Figure 10 was used for testing of these open type statorettes in high-vacuum and argon. Figure 11 gives a schematic diagram of the electrical corona test equipment.

Test data plotted in Figures 12 through 16 show corona discharge starting at 800-volts RMS or higher at winding temperature up to 1100°F in nearly all of the statorettes tested. There is no evident reason why a lower apparent starting voltage was observed at 3200-Hz in the No. 4 statorette. Initiation of corona discharge under vacuum in the 10^{-6} and 10^{-7} torr range produced only a moderate disturbance of the electrical wave form as observed on the oscilloscope. The same curves show the average starting voltage for electrical glow discharge in argon gas at atmospheric pressure to be of the order of 400-volts RMS, except in the case of statorette No. 4. It showed breakdown at 500 to 600-volts for the 600°F statorette temperature and at 250 to 400-volts for 900°F. In all cases, the initiation of electrical glow discharge in argon gas placed a sudden increase in current load on the power supply.

b. Transition Member

The six Inconel 600 clad columbium-1% Zr sheets, received from the DuPont Explosives Department, have not been evaluated beyond visual inspection. The wide extremes of surface quality were evident in the photographs included in the last quarterly report.

Figure 10. Set-Up For Testing of Open Type Statorettes In High-Vacuum and Argon

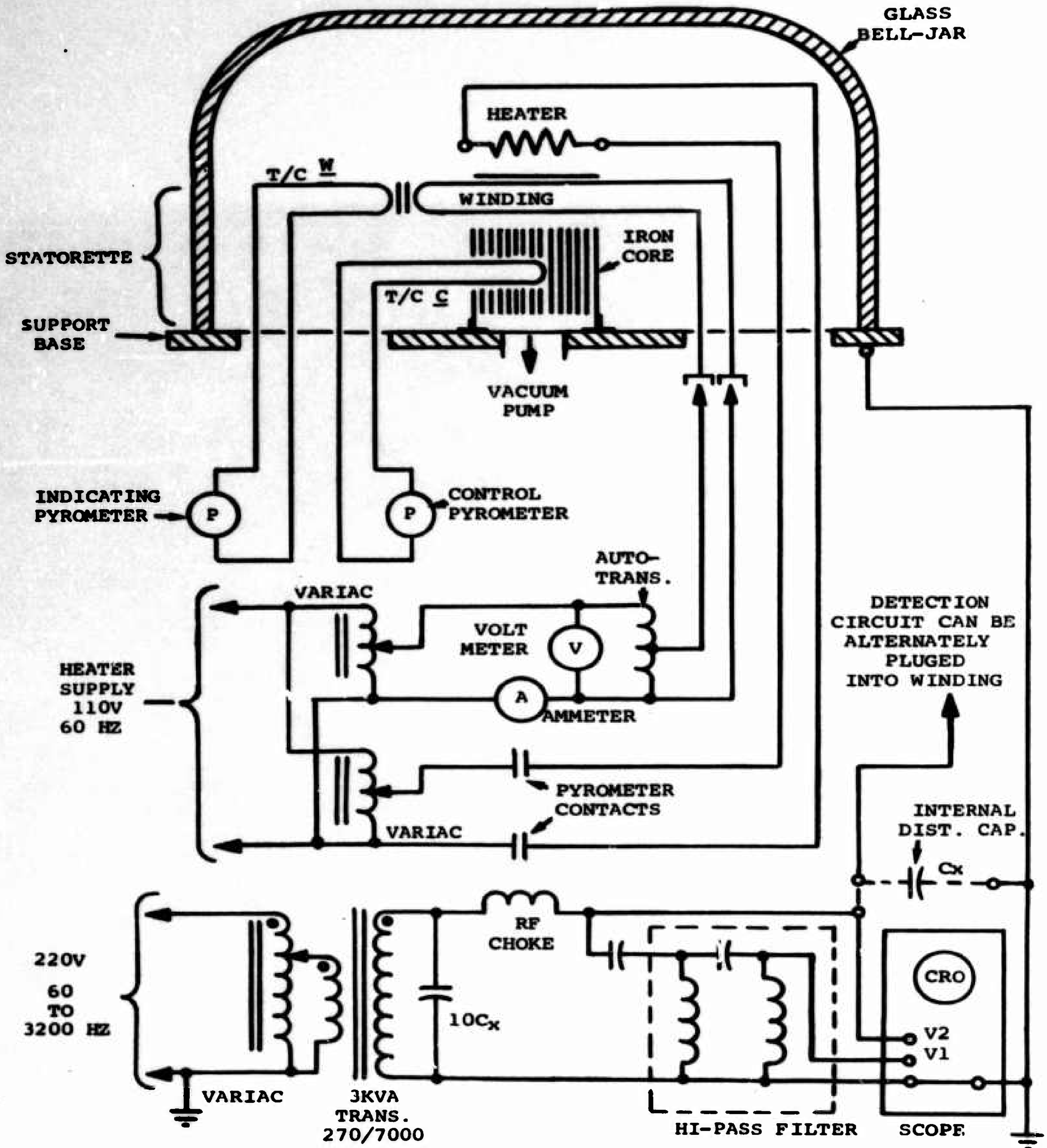
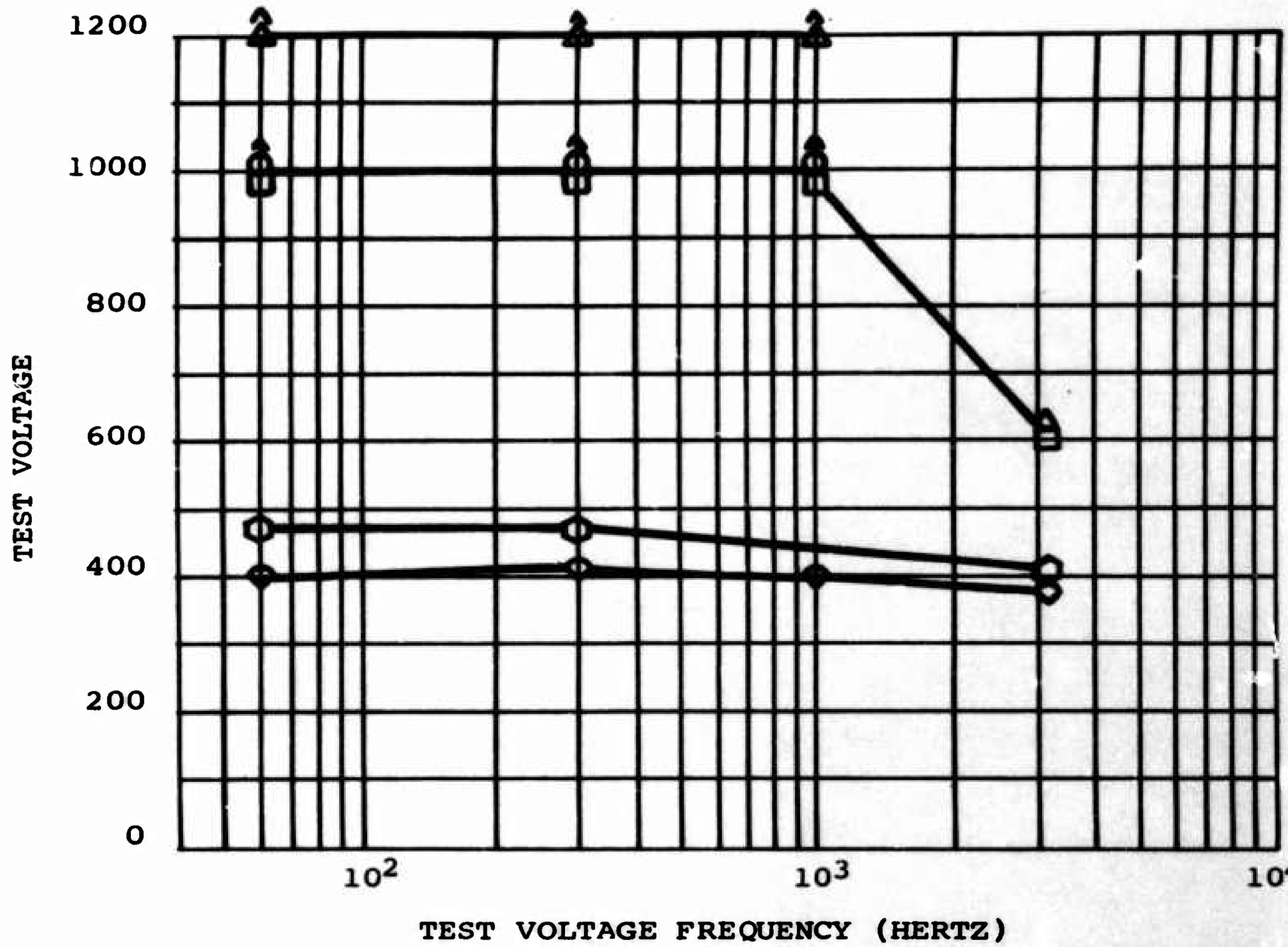


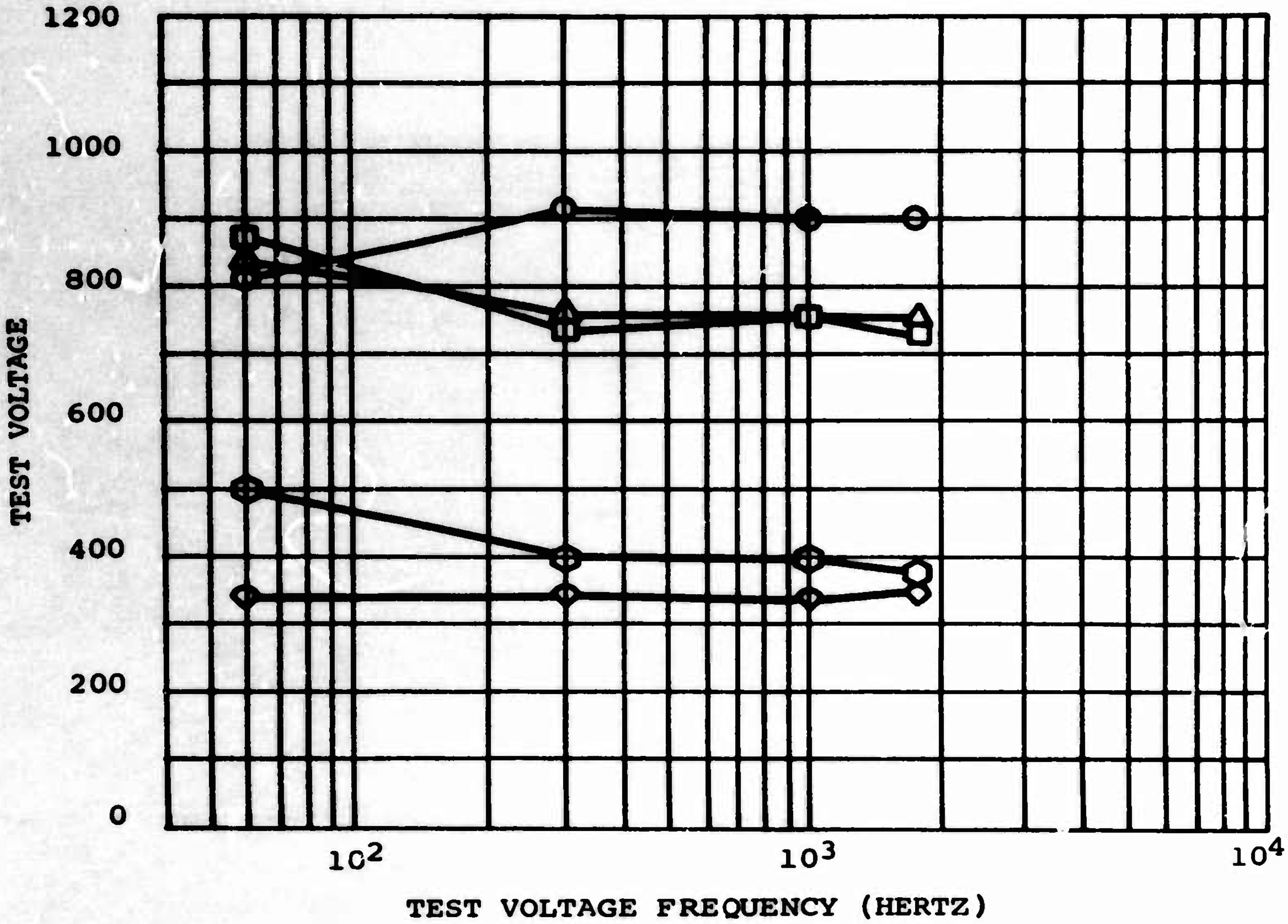
Figure 11. Schematic of Corona Statorette Test

WAED 66.52E-17



○ Starting Voltage In Vacuum At 600°F
□ Starting Voltage In Vacuum At 900°F
△ Starting Voltage In Vacuum At 1100°F
⬡ Starting Voltage In Argon At 600°F
◇ Starting Voltage In Argon At 900°F
^ Indicates Starting Voltage Higher Than Plotted Test Point

Figure 12. Glow Discharge Starting Voltages For Statorette No. 2 In High-Vacuum And In Argon



- ○ Starting Voltage In Vacuum At 600°F
- □ Starting Voltage In Vacuum At 900°F
- △ Starting Voltage In Vacuum At 1100°F
- ⬡ Starting Voltage In Argon At 600°F
- ◇ Starting Voltage In Argon At 900°F
- ∧ Indicates Starting Voltage Higher Than Plotted Test Point

Figure 13. Glow Discharge Starting Voltages For Statorette No. 3 In High-Vacuum And In Argon

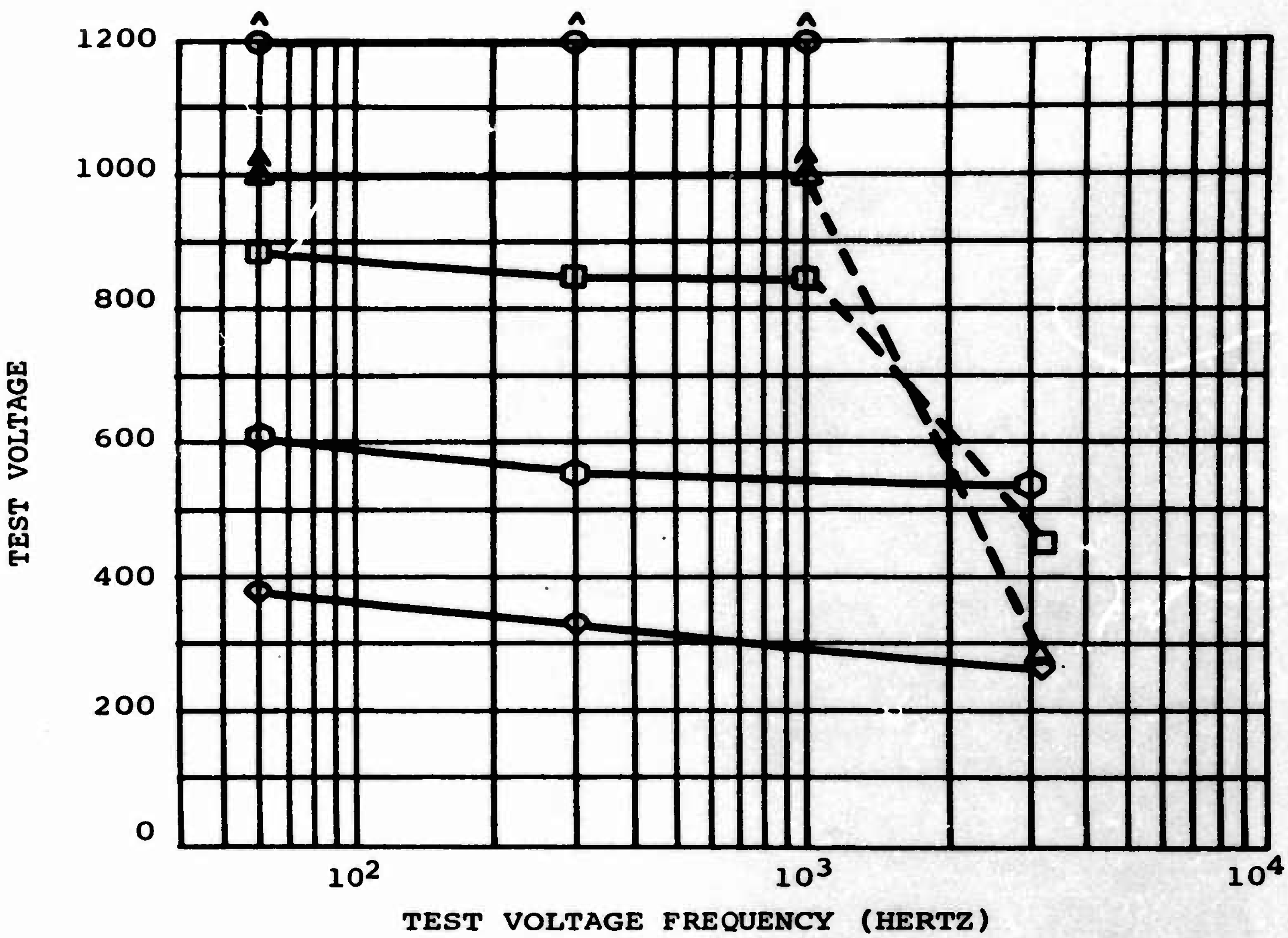
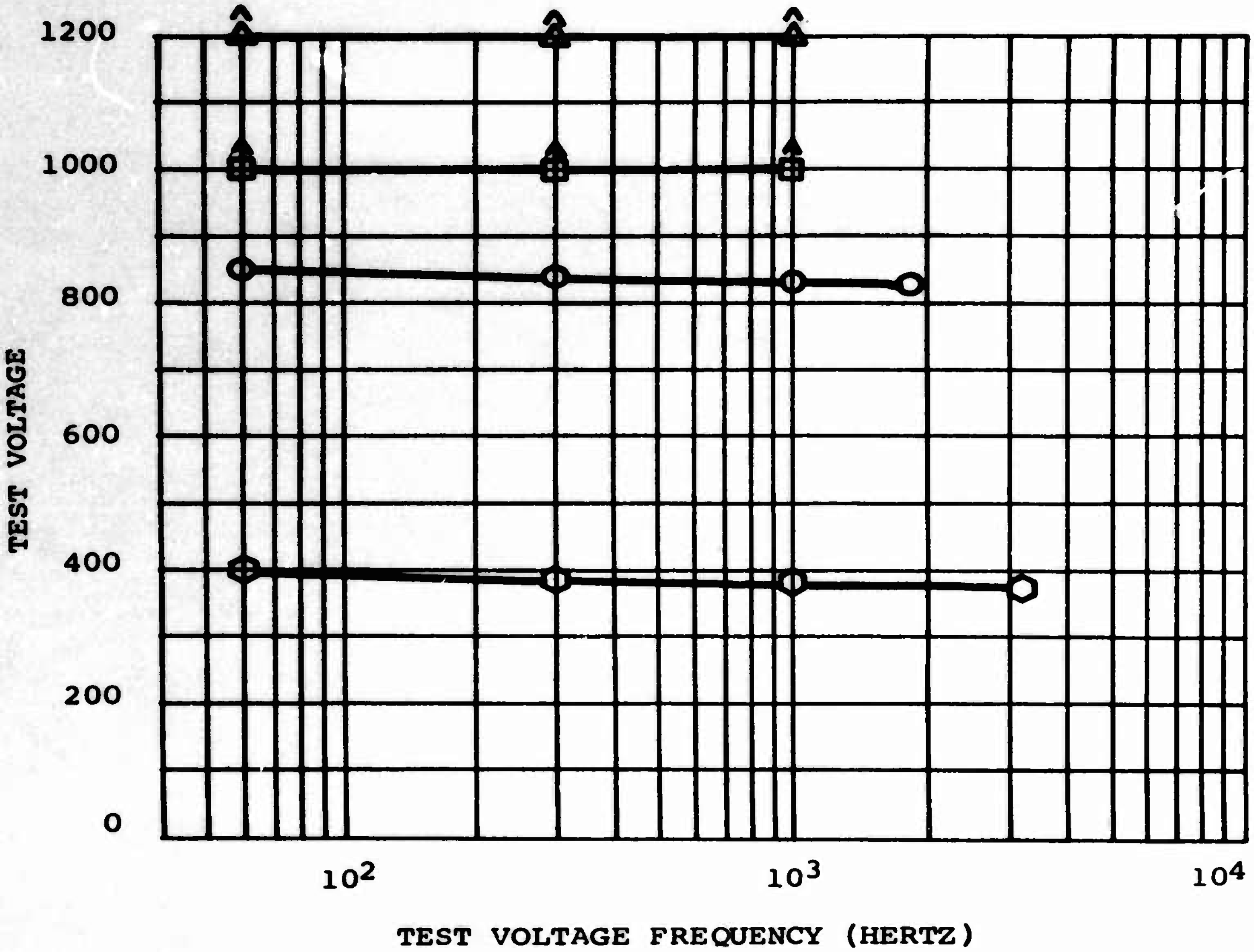
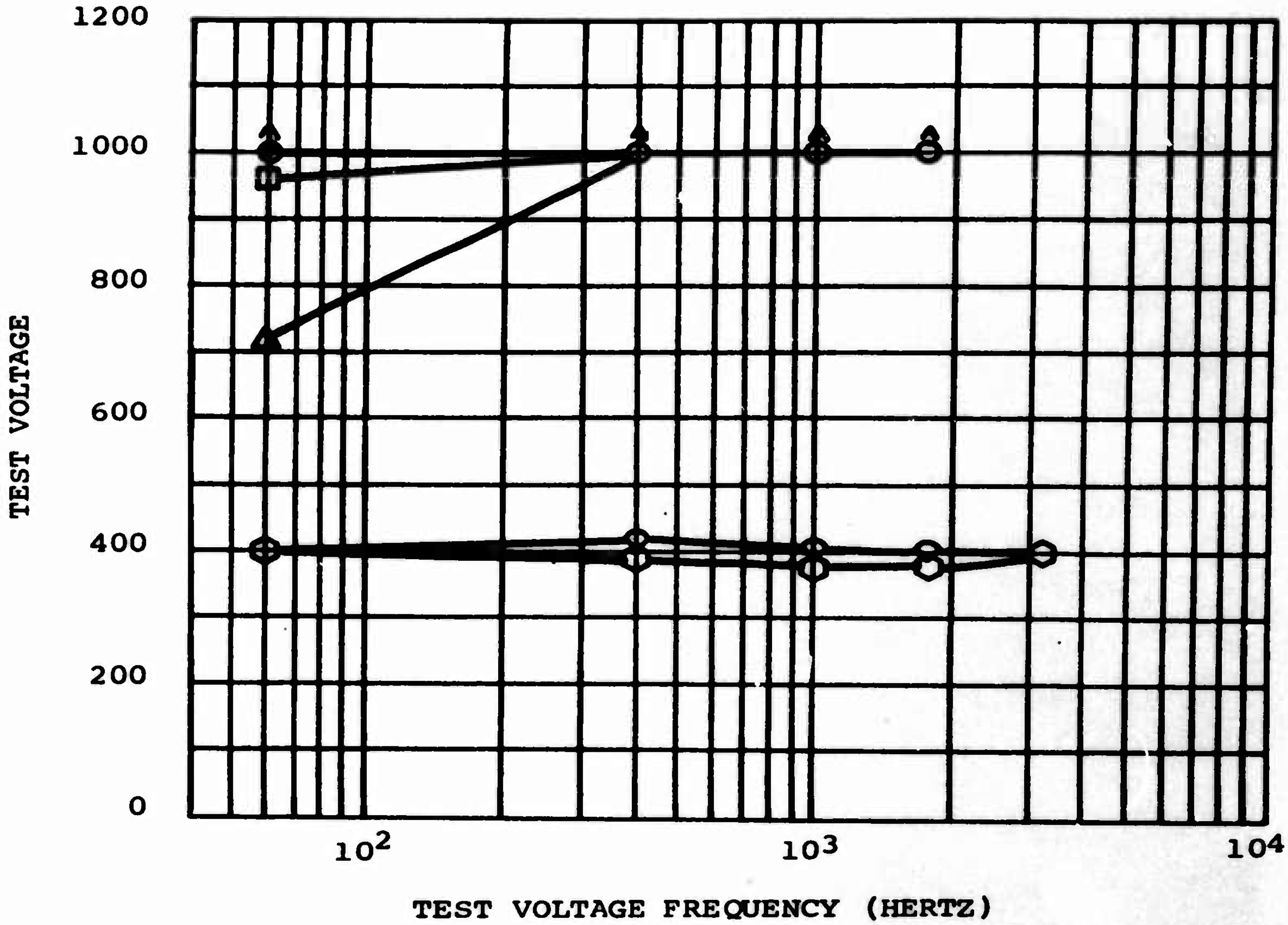


Figure 14. Glow Discharge Starting Voltages For Statorette No. 4 In High-Vacuum And In Argon



○ Starting Voltage In Vacuum At 600°F
□ Starting Voltage In Vacuum At 900°F
△ Starting Voltage In Vacuum At 1100°F
⬡ Starting Voltage In Argon At 600°F
◇ Starting Voltage In Argon At 900°F
^ Indicates Starting Voltage Higher Than Plotted Test Point

Figure 15. Glow Discharge Starting Voltages For Statorette No. 5 In High-Vacuum And In Argon



○ Starting Voltage In Vacuum At 600°F
□ Starting Voltage In Vacuum At 900°F
△ Starting Voltage In Vacuum At 1100°F
⬡ Starting Voltage In Argon At 600°F
◇ Starting Voltage In Argon At 900°F
Λ Indicates Starting Voltage Higher Than Plotted Test Point

Figure 16. Glow Discharge Starting Voltages For Statorette No. 6 In High-Vacuum And In Argon

2. <u>Planned Activity for Next Quarter</u>

a. <u>Electrical Insulation</u>

Development work under this task has been completed.

b. <u>Transition Member</u>

No further effort is planned to complete the evaluation of the Inconel 600 clad 1% Zr material because of funding uncertainties.

C. TASK 2.4.3 - ROTOR DEVELOPMENT

1. Past Quarter's Accomplishments

a. Materials Tests

The rough draft of the Rotor Materials Topical Report has been prepared and edited. Approval copies are presently being prepared for submittal to the Air Force.

b. Fluid Dynamic Tests

The Fluid Dynamic Test report was completed and published as Westinghouse Report No. WAED 66.40E.

2. Planned Activity for Next Quarter

The Rotor Materials Topical Report will be completed and published.

The Fluid Dynamic Test Report will be included as an Appendix to the Final Design Summary Topical Report.

D. TASK 2.4.4 - FULL-SCALE GENERATOR DEVELOPMENT

1. Past Quarter's Accomplishments

Maximum effort was expended in completing the manufacture of the remaining static test components, namely the No. 1 Rotor and Stator. No work was done on the No. 2 Rotor.

The 0.004-inch thick stator laminations were coated with aluminum-orthophosphate to an average double thickness of 0.00014 inches. Figure 17 is representative of the appearance of the laminations after the coating is applied. The laminations were built into stacks by aligning on an arbor as illustrated in Figure 18. The stack outer diameters were machined to size while still on the building arbor.

The stacks were then inserted into the frame, clamped, and pinned in place. The inner field coil was placed between the two stacks prior to inserting the second stack. The inner field coil was covered with an encapsulating compound of aluminum-orthophosphate and zirconium silicate. Figure 19 shows the encapsulating compound in place over the inner field coil and between the tubes. Figure 19 also shows the aluminum oxide sheet-insulation cemented in place on the cooling fins and on the sides of the frame pieces. The outer field coil was wound in six segments. The end connections were brazed in a reducing atmosphere (15% H_2, 85% Argon) with a 65% copper, 35% gold brazing alloy, using carbon resistance tongs. Careful examination of the brazed joints revealed two joints to be unsatisfactory. These joints will require rebraze.

Search coils were wound on the No. 1 Rotor completing it for the static tests. The static test rig bearings and bearing housings were fitted to the rotor and measurements were made of rotor eccentricity with respect to bearing center of rotation. Eccentricity was measured at 0.0001 inch at one set of poles and 0.0002 inch at the other.

The Final Design Summary Topical Report has been written and is being edited prior to submittal for AF approval.

2. Planned Activity for Next Quarter

Because of funding difficulties, future hardware

Figure 17. 0.004 Inch Stator Lamination Coated With Aluminum-Orthophosphate

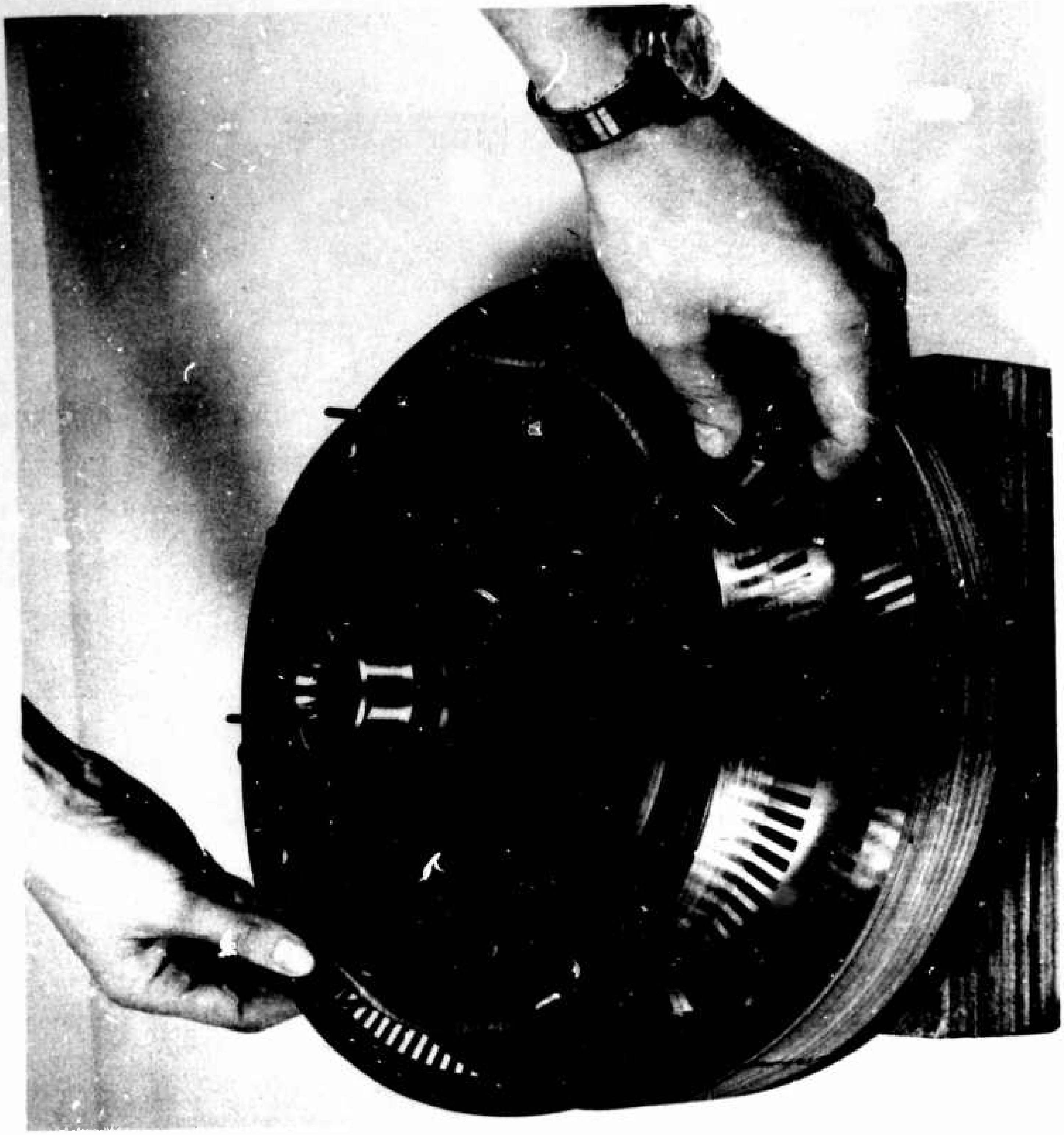


Figure 18. Stator Stack Building Arbor

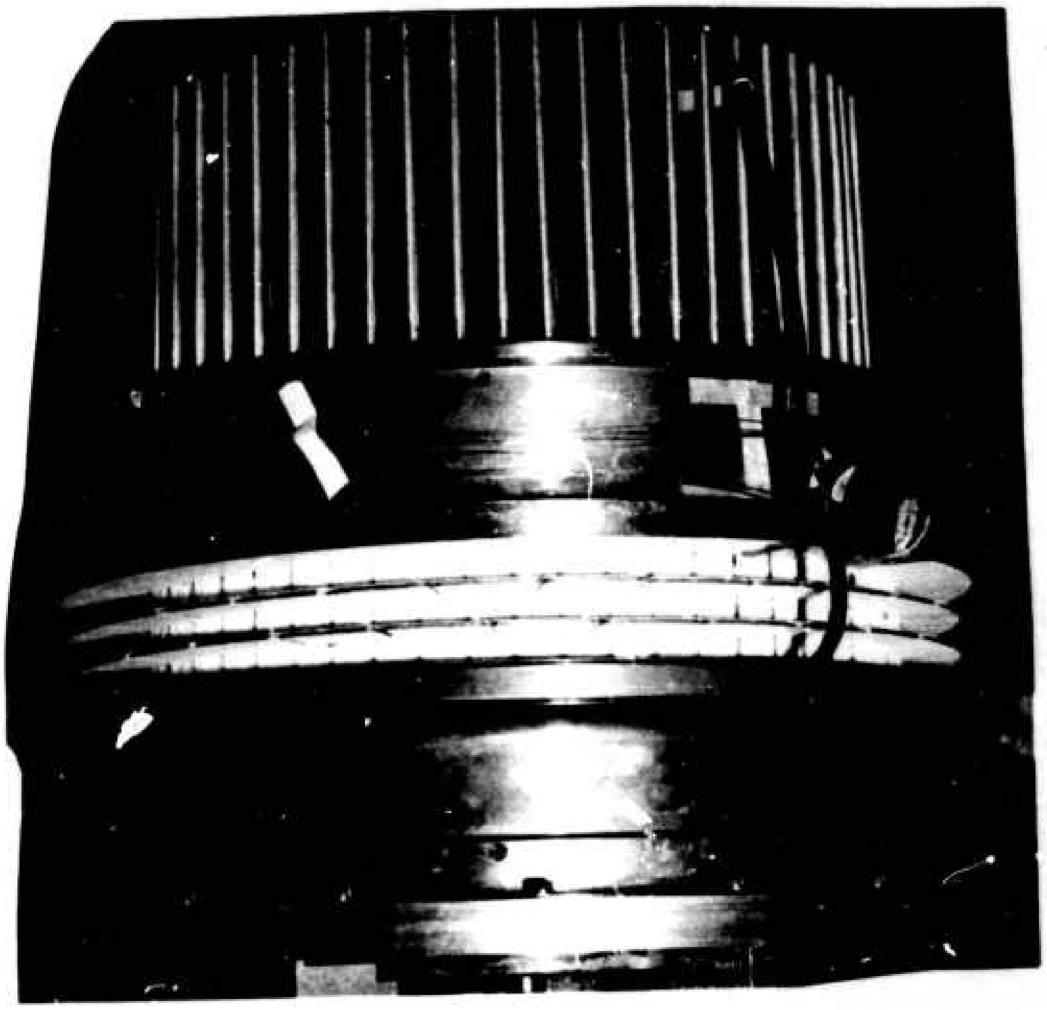


Figure 19. No. 1 Stator with Inner Field Coil Encapsulated

effort is uncertain.

The Final Design Summary Topical Report will be completed in the rext quarter.